

REASSESSMENT OF THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS EXPERIENCING INCREASES IN LEVELS OF EXPOSURE

Objective

The original assessment of the risk of foliar ozone injury on vegetation for parks in the 32 Vital Signs Networks was conducted in 2004 and used ozone exposure and soil moisture data for 1995 through 1999. This reassessment uses monitoring data for ozone from 2000 through 2004 to update the risk assessments for selected parks. Together the two assessments provide insight to the changes in ozone exposure over a ten-year period, and examine how the changes may have altered the risk of ozone injury to plants.

The reassessment of risk was conducted for Craters of the Moon National Historic Park, Death Valley National Park, Grand Canyon National Park, Great Basin National Park, Mesa Verde National Park, Rocky Mountain National Park, Sequoia and Kings Canyon National Park, and Yellowstone National Park. These parks were selected because it appeared they experienced increased levels of ozone exposure since the initial assessment. This document contains the reassessment for Craters of the Moon National Historic Park. Other reassessments can be accessed from the appropriate park's AQRV page on ARIS at <http://www2.nature.nps.gov/air/Permits/ARIS/>.

Risk Assessment Methodology

The risk assessment is based on a triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003, a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a

comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in

producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to -4.0 , a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

Literature Cited

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Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. *Atmospheric Environment* 31(11):1695-1708.

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CRATERS OF THE MOON NATIONAL HISTORIC PARK (CRMO)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Amelanchier alnifolia</i>	Saskatoon serviceberry	Rosaceae
<i>Apocynum androsaemifolium</i>	Spreading dogbane	Apocynaceae
<i>Populus tremuloides</i>	Quaking aspen	Salicaceae
<i>Salix scouleriana</i>	Scouler's willow	Saliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone monitored on-site were analyzed to generate annual exposure values. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for CRMO					
	1995	1996	1997	1998	1999
Sum06	1	12	2	10	11
W126	12.2	19.9	9.8	22.7	5.4
N60	20	223	40	267	234
N80	0	5	0	0	2
N100	0	0	0	0	0

Ozone air quality data for CRMO					
	2000	2001	2002	2003	2004
Sum06	17	0	19	19	6
W126	25.1	6.2	32.5	31.4	21.3
N60	357	13	465	447	165
N80	0	0	0	5	0
N100	0	0	0	0	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at CRMO					
	1995	1996	1997	1998	1999
Month 1	1.12	-1.49	-0.05	3.52	1.91
Month 2	4.49	-0.21	1.05	3.11	1.12
Month 3	7.03	-1.66	3.38	2.15	1.52

Palmer Z Index data for 3-month Sum06 period at CRMO					
	2000	2001	2002	2003	2004
Month 1	-3.72	-0.90	-1.41	-1.82	0.05
Month 2	-2.65	-4.17	-2.03	-3.82	-0.60
Month 3	-2.78	-3.78	-2.54	-4.15	-0.04

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at CRMO					
	1995	1996	1997	1998	1999
April	1.12	0.30	1.04	-0.26	2.33
May	4.49	2.95	-0.05	3.52	3.61
June	7.03	-1.49	1.05	3.11	1.91
July	5.41	-0.21	3.38	2.15	1.12
August	3.05	-1.66	3.01	-0.99	1.52
September	-0.15	0.41	1.59	1.92	-1.66
October	-0.71	-0.55	0.60	-0.70	-1.57

Palmer Z Index data for the 7-month W126 period at CRMO					
	2000	2001	2002	2003	2004
April	-1.53	- 0.90	0.11	1.71	-1.06
May	-1.77	- 4.17	-1.41	-1.82	0.05
June	-3.72	- 3.78	-2.03	-3.82	-0.60
July	-2.65	- 2.61	-2.54	-4.15	-0.04
August	-2.78	- 2.44	-2.37	-1.89	0.59
September	-0.41	- 1.30	0.36	-1.26	-0.08
October	2.03	- 0.87	-0.71	-2.72	3.10

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.

1995-1999

- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value generally exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show only two years in which concentrations exceeded 80 ppb and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- Soil moisture levels were generally normal and favored the uptake of ozone. Four months of mild drought were distributed among two of the years. With this incidence of drought, it is not possible to determine whether a relationship exists between the level of soil moisture and either the 90-day cumulative Sum06 or the seasonal W126 index of exposure.

2000-2004

- The Sum06 index generally exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone never reached 100 ppb, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 threshold was usually achieved each year while the W126 criteria were not satisfied in any of the five years.
- The N-values for the site show concentrations frequently exceeded 60 ppb. There was one year in which concentrations exceeded 80 ppb for five hours, and no years in which concentrations reached 100 ppb. These levels of exposure are not likely to injure vegetation.
- There are no associations between the levels of ozone and soil moisture conditions for either the Sum06 or W126 indices of exposure. There were two or three months of drought in four of the years in which the Sum06 index was calculated. For the W126 index, four to six consecutive months of mild to severe drought occurred in four of the years. These conditions can significantly constrain the uptake of ozone and reduce the probability of foliar injury. Only one year had near normal moisture conditions.

The levels of ozone exposure and soil moisture conditions at Craters of the Moon National Historic Park make the risk of foliar ozone injury to plants low. The Sum06

index of exposure increased over the ten-year assessment period. While the W126 cumulative value also increased over this period, exposure levels never reached 100 ppb. The hours of exposure greater than 60 ppb increased in occurrence over the ten-year period, however ozone only rarely exceeded 80 ppb. Soil moisture levels were generally favorable for the uptake of ozone in the 1995 to 1999 period, but five to seven months of mild to severe drought occurred in most years during the second five-year period. Drought at this level would significantly restrict the uptake of ozone. Collectively, the ambient levels of exposure and soil moisture conditions are such that the threshold for foliar injury is not likely to be reached.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: spreading dogbane, quaking aspen, and Scouler's willow.